Near - IR and color imaging for bruise detection on Golden Delicious apples

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ABSTRACT

Digital images of reflected light in both the near - infrared (NIR) and visible wavelengths from the surface of bruised and unbruised Golden Delicious were captured for classifying bruise damage. Each of the attributes of two models for color representation, RGB and HSI, were compared to NIR for their ability to discriminate bruised from unbruised tissue. The surface reflectance for good tissue decreased from the fruit center outward, except saturation which increased. Reflectance of good tissue also varied adjacent to the bruised area compared to a location 60 degrees away. NIR, green, hue and red were the features which showed the most contrast between bruised and undamaged tissue. This contrast did not decrease for green, red, and hue as storage time increased.

INTRODUCTION

The appearance of a Golden Delicious apple is the primary factor on which the consumer makes a purchasing decision. The consumer expects bruise and blemish free fruit. The eye is a sensitive sensor of spectral reflectance from the apple surface to judge overall quality. As the technology became available, it was only natural for scientists to measure surface reflectance to quantify apple quality and maturity. Early work used the spectral reflectance for wavelengths from 400 - 700nm to characterize changes in color as the fruit matures.[1,2] This information was used to measure ripeness on Golden Delicious.[3] The values were converted to CIE chromaticity values and correlated with picking dates.[4]

Mechanical injury of Golden Delicious apples can result in softening and discoloration of the tissue under the apple's skin. The discoloration or browning of fruits is ascribed to the oxidation and polymerization of phenolic compounds.[5,6] Unlike red cultivars which tend to mask the browning, the partially translucent yellow skin of Golden Delicious apples allows the browning to show through the skin in sharp contrast to the uniform fruit color. Spectral reflectance at 600nm was used to measure browning on Golden Delicious apples and was correlated with time and temperature.[7] Discoloration was expressed as the difference between normal and injured tissue reflectance.[7] Golden Delicious were found to discolor erratically and more slowly than other

cultivars and temperature was found to have little effect on the rate of browning.[7] The reduction in surface reflectance between normal and bruised tissue for Golden Delicious was found to be about 8% compared to 11% for red cultivars such as Red Delicious and McIntosh.[8] Surface reflectance using wavelengths between 700 - 2200nm was reduced for bruised compared to normal Golden Delicious tissue.[8] The signifigance of this finding is that it removed color variations from the reflectance measurement for bruised tissue. The reflectance properties for peeled and unpeeled Golden Delicious were found for the wavelength range 350 to 800 nm.[9] All of the above surface reflectance measurements were made with spectrophotometers and would not be applicable to high speed measurement required in packing lines.

Digital image processing was developed to measure surface reflectance over the total fruit surface to find areas of lower surface reflectance which could be bruises.[10] This method could rapidly measure surface reflectance of a stream of apples on the packing line. Linear discriminate classifiers were determined by using a training set of apples with known bruise areas.[10] Predicting bruised tissue on Golden Delicious apples by measuring the NIR surface reflectance for wavelengths between 750nm to 850nm showed correlations to actual bruising of 0.22 compared to 0.72 or better for Red Delicious and McIntosh.[10] When the apples were cut after testing, a layer of good tissue cells was found just under the skin of the Golden Delicious; unlike Red Delicious and McIntosh which had damaged cells.[10] This observed reduction in surface reflectance in both the visible and NIR wavelengths for bruised tissue on Golden Delicious apples leads to the objective of this research. An automatic detection system to size and find defects on Golden Delicious apples using data reduction enabled apples to be scanned at a rate of five fruit per second but could not separate bruised fruit.[11]

OBJECTIVE

Examine digital imaging of diffuse surface reflectance both in the visible and NIR spectrums as methods for detecting bruises on Golden Delicious apples. Determine which features of reflected light (NIR,RGB,and HSI) are the most effective for detecting damaged tissue on Golden Delicious apples before and after storage.

MATERIAL AND METHODS

Two samples of 88 Golden Delicious apples were hand harvested in mid-September during the 1991 harvest season at the Applachian Fruit Research Station in Kearneysville, WV. Each apple was placed in tray packs and stored in a cold room at 1^0 C until needed for testing. A 39 mm diameter steel disk was dropped onto the surface of each fruit.[12] Samples were held for 24 hours at 20^0 C to allow full bruise development and then digital images were captured (time 1). Thereafter, images were grabbed twice at one month intervals (time 2 and time 3). The apples were removed from cold storage 24 hours prior to imaging and held at 20^0 C.

A slightly translucent arcylic plastic diffuser mounted in front of

eight tubular tungsten lamps ([1]General Electric 40A, 40 W) mounted in the apple lighting chamber provided uniform diffuse illumination of the apple surface.

Color images of one sample of 88 apples were acquired by digitizing the output from a RS-170 solid-state camera. A DEC-IPS (Kontron Electronics) image processing system connected to a MicroVax II (Digital Equipment Corp) was used to acquire RGB color images. The DEC-IPS consisted of a frame grabber, image processor, video memory, and image processing software. A 25mm lens with an aperture set at f4.0 was mounted to a color CCD camera (Model M-852, Micro Technica). To standardize images from one date to another, the gain for each color band was adjusted while viewing a Teflon cylinder. Each color band was independently adjusted to a mean grey level: red-142, green-199, blue-189. The RGB images were transported to a PC-based system equipped with a frame grabber (DT2871), frame processor (DT2858), and a library of image processing functions (AURORA, Data Translation Inc.) where they where converted to HSI color images.

NIR images were acquired of a second sample of 88 apples by digitizing the RS-170 output of a CCD array camera (Model 4810, COHU Electronics). A PC-based system equipped with a frame grabber (DT2851), frame processor (DT2858), and image processing library functions (DTIRIS, Data Translation Inc) captured the NIR images. A 25mm lens with an aperture set at f1.4 was mounted to the camera with a long pass filter (Kodak Wratten 89B) placed in front of the lens to limit the light viewed by the camera to the NIR wavelengths.[4]

Two 512 vertical pixel x 512 horizontal pixel images of every apple were acquired; one with the bruise centered on the axis of the lens and a second with the bruise rotated (about the apple's stem/calyx axis) 60 degrees away from the lens axis displaying only undamaged tissue.

Image processing of all of the images consisted of interactively locating and recording the location of the center of the bruised area. The mean pixel value (0 to 255) of pixels at 1 degree intervals about the circumference of three concentric rings of three different diameters were recorded. Figure 1 shows the location and relative size of the three rings. Ring 1 had a fixed diameter of 10 pixels. Ring 2 had an approximate diameter equal to the bruise diameter (80-90 pixels or 20-25mm) minus 25 pixels. Ring 3 had an approximate diameter equal to the bruise diameter plus 25 pixels. The mean pixel values for both bruised and unbruised tissue (apple rotated 60^0) centered on the location of the bruise center were recorded for NIR, RGB, and HSI Golden Delicious apple images captured at the three different storage times.

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[1] Mention of specific products is for the information of the reader only and is not considered an endorsement by Cornell University, USDA-ARS, or the authors.

RESULTS AND DISCUSSION

To determine the variations in reflectance from the surface at the apple's center outward to the apple's edges, a two sample t-test was performed to determine if the mean pixel values of the three concentric rings located on unbruised tissue are different from each other. Figures 2 and 3 show the mean pixel values of unbruised tissue for the three rings located at 60 degrees to the bruise center. It was found that the means for ring 3 were significantly different from means of rings 1 and 2 ($p<0.01$), specifically higher for NIR, green, blue, hue, saturation and intensity and lower for red. The same test was performed on rings 1 and 2 (0 degrees), bruised tissue, which determined that the means for NIR and hue were significantly different for the two ring sizes ($p<0.05$). For all tests except saturation, as the ring diameter increased, there was a trend of the mean pixel value declining. Saturation showed the reverse, as the ring diameter increased, the mean pixel value showed an increasing trend. Therefore, there is a geometric effect because of the surface curvature of the apple.

The reflectance variability of undamaged tissue values around each fruit may vary from location to location. The mean pixel values of the two largest rings (ring 3 at 0 and 60 degrees) were compared. Comparing the mean values for these rings in Figures 2 and 3 shows that the mean pixel value for red, green, blue, hue, saturation, and intensity for unbruised tissue was significantly different ($p<0.01$). This test showed that there was less red, more green, more blue, greater hue, less saturation, and more intensity on the unbruised side of the sample compared to the bruise side. The sample could have been by chance a different color on one side compared to the other or there could be effects on the reflectance from the large ring of undamaged tissue around the bruised area caused by internal interactions in undamaged cells adjacent to bruised tissue.

Because of the reflectance difference from the smallest (ring 1) to the largest ring (ring 3) and the variations found for the two large rings spaced 60 degrees apart, it was decided that the best contrast for comparing bruised and undamaged tissue would be found between ring 2 inside the bruise and ring 3 located just outside and concentric with the bruise. Figure 4 shows the mean found by averaging the difference of the mean pixel values of the two rings for each apple. The standard deviations are also shown. A t-test was performed to see which mean had the greatest difference from 0. NIR was found to have the greatest difference, followed in descending order by hue, green and red. Saturation, blue and intensity were found to be different from 0, but by a much smaller t-value caused mainly by their large standard deviations. NIR, green, hue and red show the most promise as reflectance features which could be used to discriminate between bruised and undamaged tissue.

Figures 5 and 6 show the changes for the reflectance features for bruised and undamaged tissue for ring 2 and ring 3 over a two month period. NIR reflectance for bruised tissue increased in the first month of storage to a value nearly equal to undamaged tissue. NIR reflectance

for undamaged tissue varied only slightly over the same period. The mean pixel value for bruised and unbruised tissue increased equally for red and decreased equally for hue. The differences in pixel values between damaged and undamaged tissue for these two features remained constant over the storage period. Blue, saturation, and intensity showed a reduced contrast between pixel values for bruised and unbruised tissue. Green showed a decrease in mean pixel values for time 2 for unbruised tissue and an equal value for bruised tissue. This resulted in a lower difference in contrast between the tissue types for time 2 only. Time 3 showed the same contrast between bruised and undamaged tissue as time 1. The color features of red, green, and hue are not effected as much by storage time as NIR. These features maintained a difference between bruised and unbruised tissue over the total storage time and may be possible features to form a discriminate function for identifying bruising on stored Golden Delicious.

CONCLUSIONS

Surface reflectance for Golden Delicious was found to decrease significantly from the fruit center outwards for the reflectance features of NIR, red, green, blue, hue, and intensity. Saturation was found to increase.

A color difference for good tissue was found between two locations, one concentric about the bruise and the other 60 degrees apart. From the data collected it was not possible to tell if this difference was an interaction from the bruising process in good tissue adjacent to bruised tissue or was a natural color variation.

NIR, hue, green, and red were more effective for discriminating bruised from undamaged tissue. Large variations in surface reflectance for blue, saturation, and intensity reduced their discriminating ability.

Red, green and hue, unlike NIR, did not show the increase in reflectance with storage time. These features could be used to form a discriminate function for identifying bruising on stored Golden Delicious apples.

ACKNOWLEDGEMENTS

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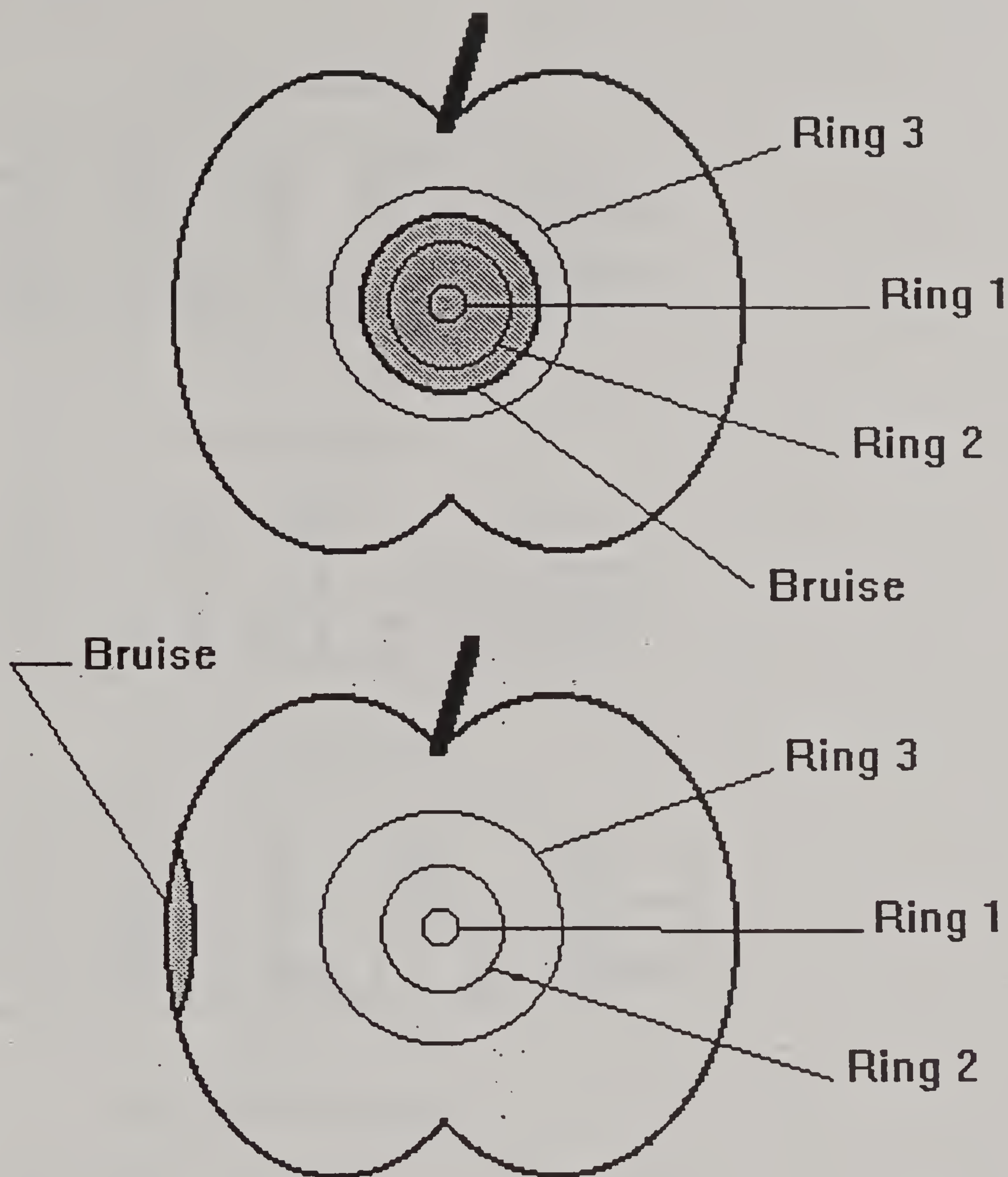


Figure 1. Diagram showing the location of the rings of pixels averaged to determine a mean pixel value for reflectance for bruised and unbruised tissue on Golden Delicious apples.

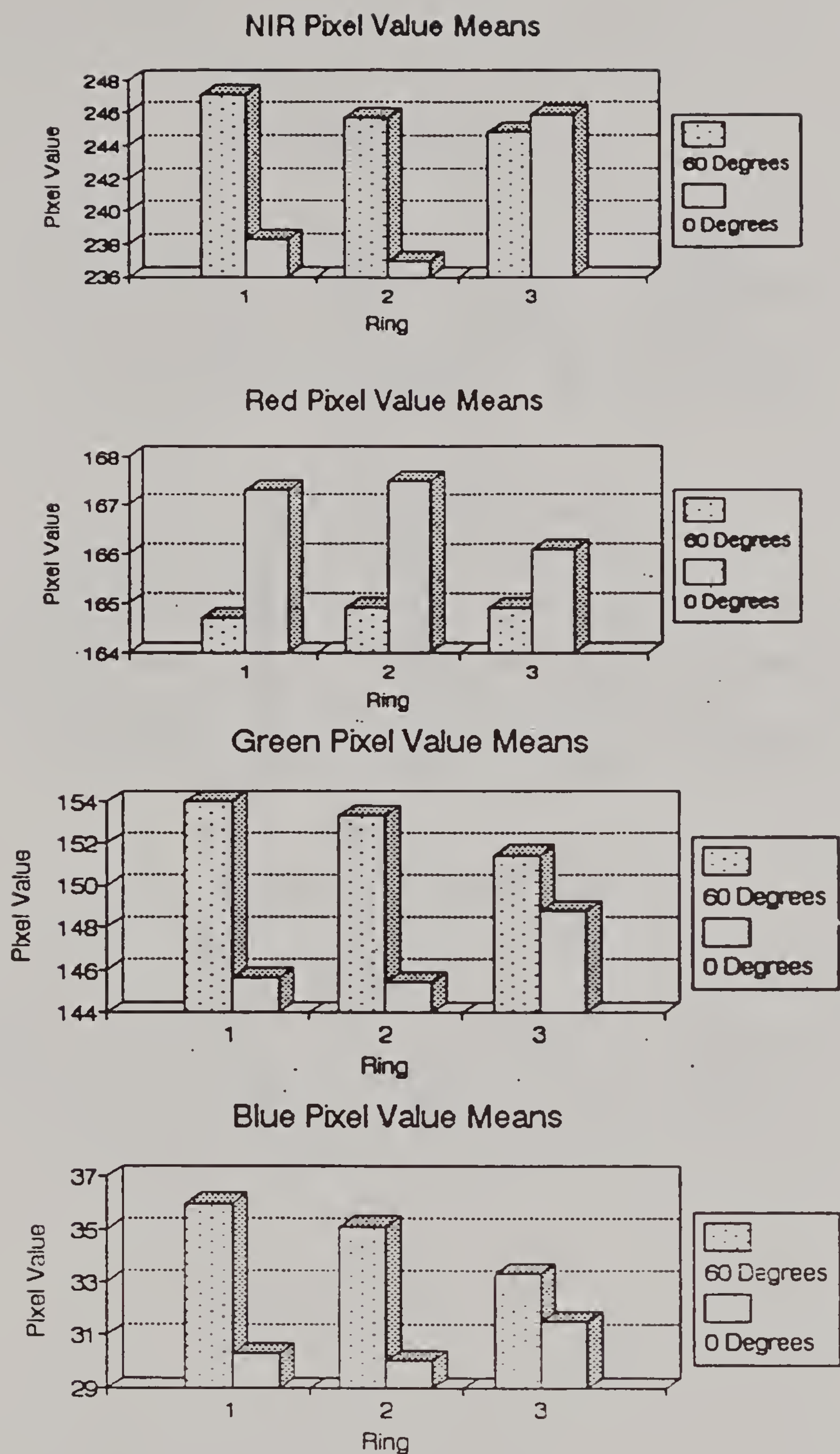


Figure 2. Surface reflectance (pixel values) 24 hours after bruising for NIR, red, green, and blue for three concentric rings both centered and 60 degrees from the bruise center are shown. Ring 1 is the smallest and ring 3 the largest. Ring 3 at 0 degrees and rings 1-3 at 60 degrees represent values for undamaged tissue.

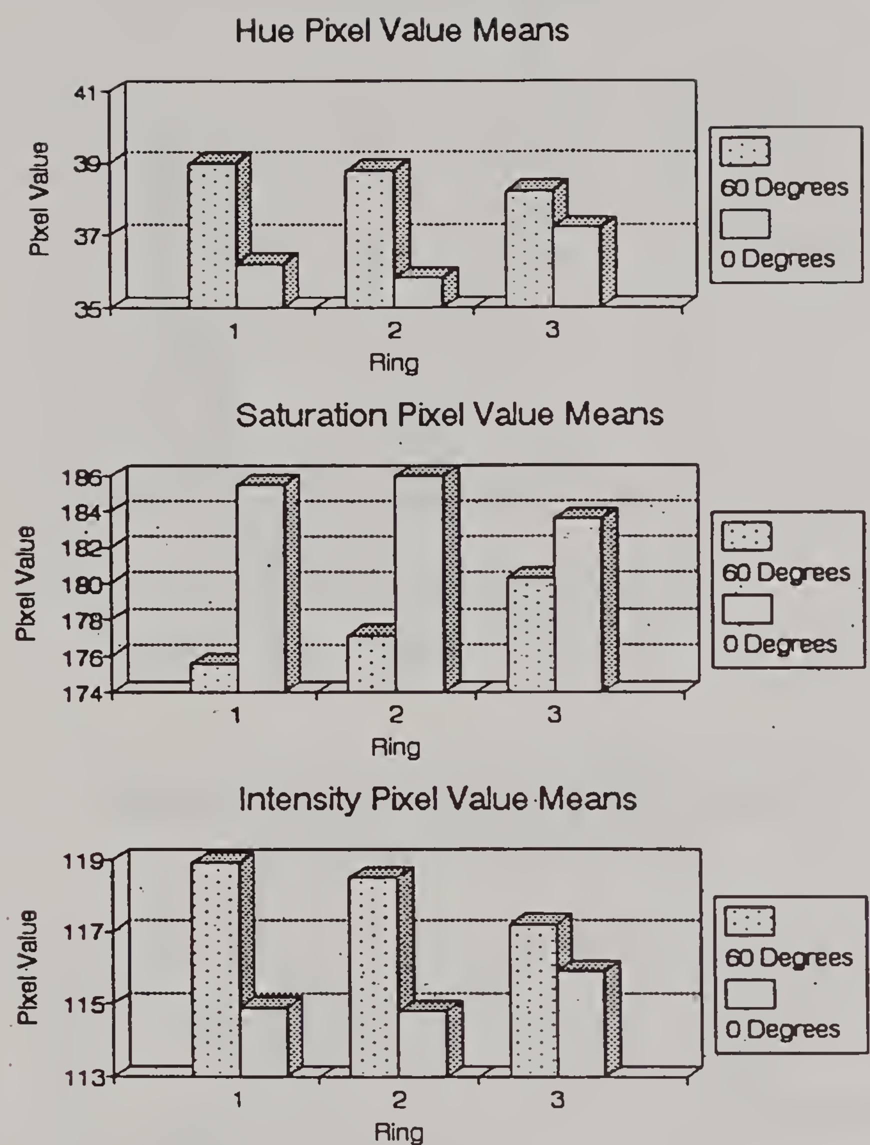
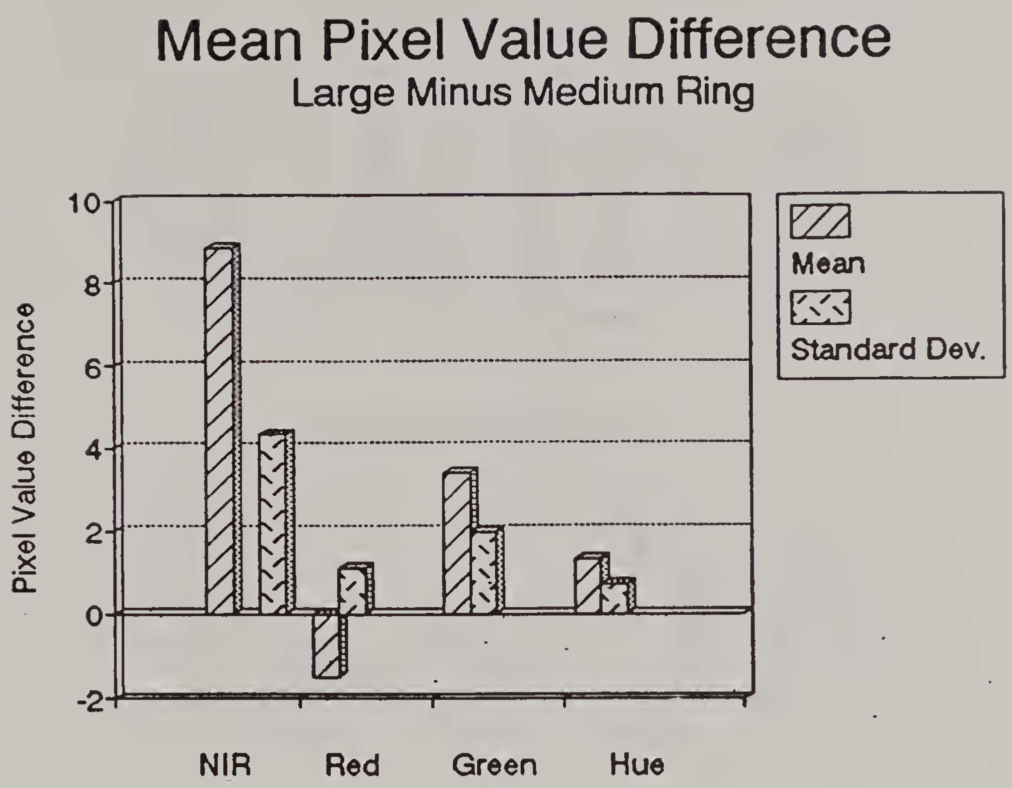


Figure 3. Surface reflectance (pixel values) 24 hours after bruising for hue, saturation, and intensity for three concentric rings both centered and 60 degrees from the bruise center are shown. Ring 1 is the smallest and ring 3 the largest. Ring 3 at 0 degrees and rings 1-3 at 60 degrees represent values for undamaged tissue.



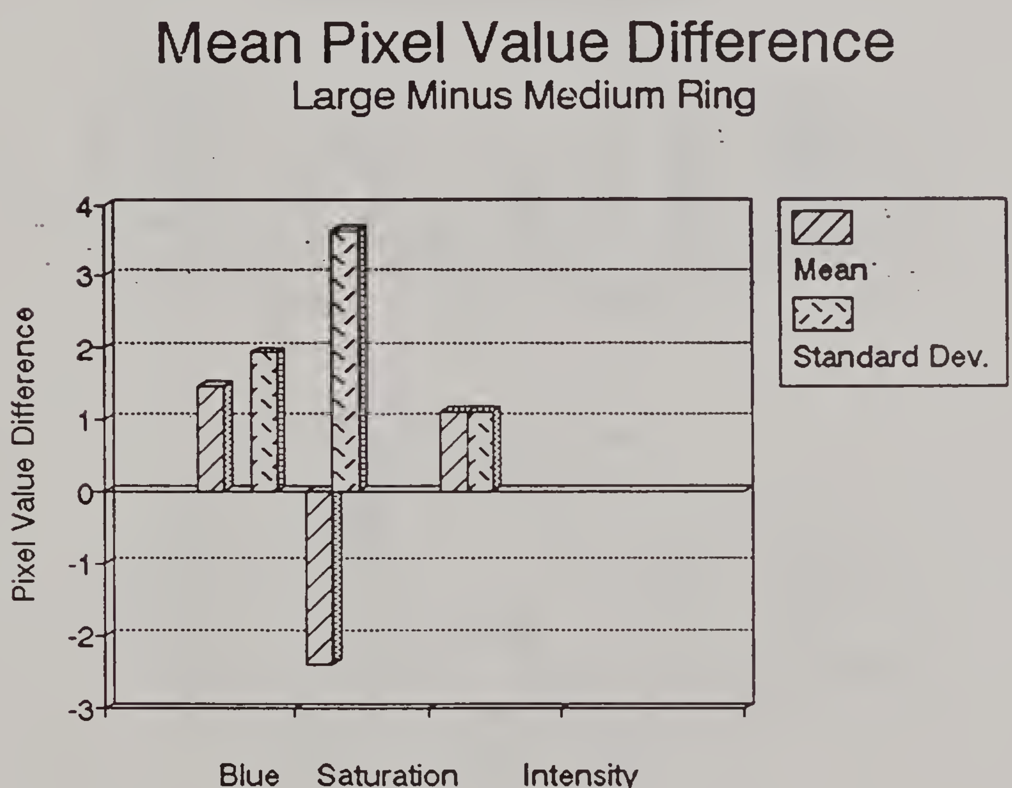


Figure 4. Mean and standard deviations of the difference of pixel values 24 hours after bruising for a medium (bruised) and large (unbruised) ring concentric about the bruise center, with ring diameters equal to the bruise diameter minus 25 pixels and bruise diameter plus 25 pixels, respectively.

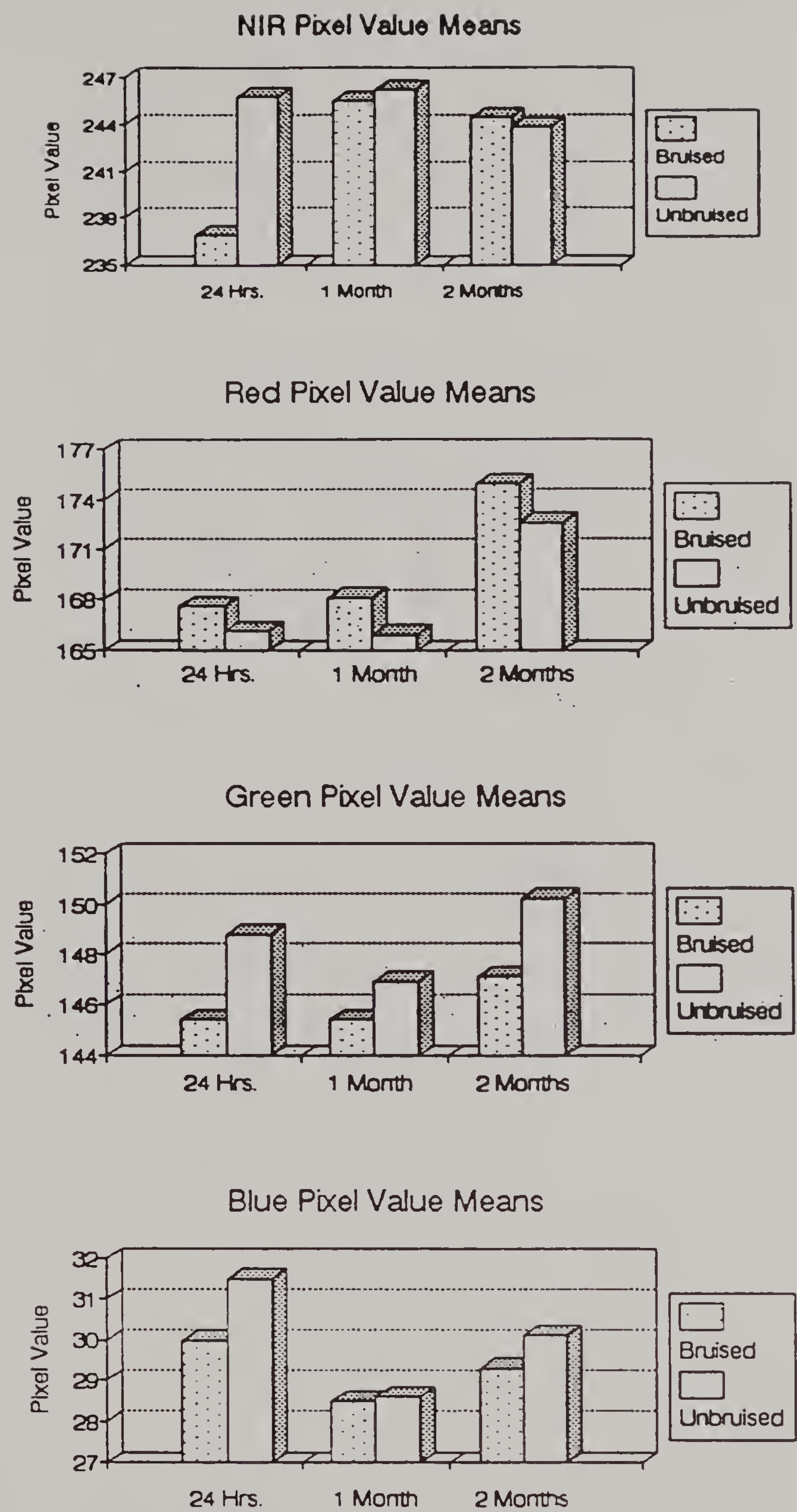


Figure 5. Pixel values representing reflectance at three storage times for NIR, red, green, and blue features using medium (bruised) and large (unbruised) rings concentric about the bruise.

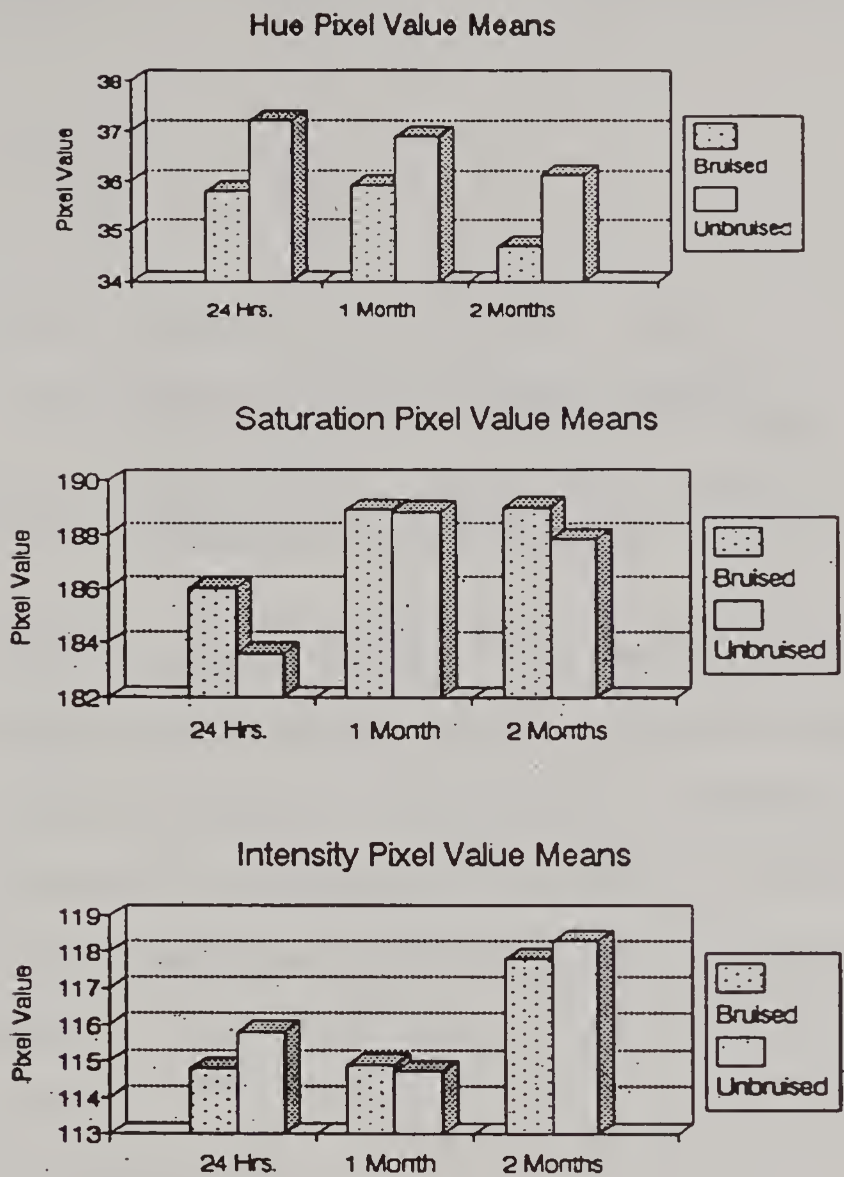


Figure 6. Pixel values representing reflectance at three storage times for hue, saturation, and intensity features using medium (bruised) and large (unbruised) rings concentric about the bruise.

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Enclosure

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D. Michael Glenn, Research Leader

FROM: Bruce L. Upchurch, Authorized Departmental Officer Designated Representative/Agricultural Engineer

Enclosed is the final report for the above Cooperative Agreement with Cornell University. In the agreement, only a final report was required. The report is complete and should be accepted. Therefore, acceptance of the report should close out the Agreement.

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